NEAREST-NEIGHBOUR ANALYSIS: A TECHNIQUE FOR QUANTITATIVE EVALUATION OF POLYGONAL GROUND PATTERNS

BY
LISA A. ROSSBACHER

Geological Sciences Department, California State Polytechnic University, Pomona

Rossbacher, Lisa A., 1986: Nearest-neighbour analysis: A technique for quantitative evaluation of polygonal ground patterns. *Geogr. Ann.* 68A (1–2): 101–105.

ABSTRACT. Nearest-neighbour analysis can be applied to polygonal ground patterns to give a quantitative evaluation of the pattern. The nearest-neighbour statistic (R) indicates the degree to which an observation departs from an expected random pattern. The R-statistic is particularly useful in comparing patterns by highlighting differences that are not subjectively obvious. Because the nearest-neighbour technique eliminates the effect of scale, it can be used to compare a variety of patterns, including ice-wedge and desiccation polygons, lava cooling cracks, and tectonic fractures. Nearest-neighbour analysis can also be applied to the large-scale polygonal ground on Mars and other planetary bodies.

Introduction

Patterned ground is a characteristic geomorphic feature in many periglacial and some arid regions of Earth (Washburn 1956). The patterns are frequently described as "regular" or "random," but these are subjective observations that have never been useful for comparisons of patterns.

Vitek (1973*a*, *b*) has applied nearest-neighbour statistics to one type of patterned ground, mound fields, in order to describe the pattern quantitatively. He adapted a technique that was devised by Clark and Evans (1954); their procedure was primarily developed to describe the distribution of vegetation, but the nearest-neighbour technique has been used in various other geographical studies of pattern. These other uses include describing the spatial distribution of towns (Barr *et al* 1971), drumlins (Smalley and Unwin 1968; Trenhaile 1971), and grocery stores (Getis 1963).

Previous attempts to describe polygonal ground quantitatively have emphasized the number of sides, polygon diameters, and the intersection angles of the outlining fractures (Kerfoot 1972). The technique discussed here uses the vertices and intersections of fractures outlining polygons as points to evaluate the randomness or regularity of the pattern. The nearest-neighbour procedure has never been used to describe polygonal ground. Besides describing the patterned ground, nearest-neighbour analysis may also be useful in understanding the climate, material, and processes that formed the pattern.

Analytical method

The nearest-neighbour statistic, R, represents the degree to which an observation departs from a predicted random distribution (Clark and Evans 1954):

$$R = \frac{\bar{r}_A}{\bar{r}_E}$$

where $\bar{r}_A$ is the mean of the observed distances between nearest neighbours and $\bar{r}_E$ is the mean expected distance in a random distribution. Possible values of R range from 0.00, maximum clustering, through 1.00, a random pattern, to 2.15, a

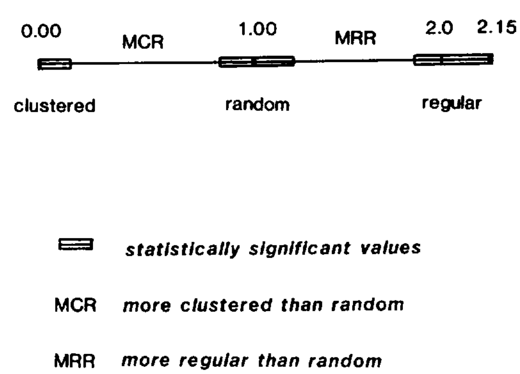

Fig. 1. The range of values for the nearest-neighbour statistic (R). After Vitek (1973*a*); used by permission.

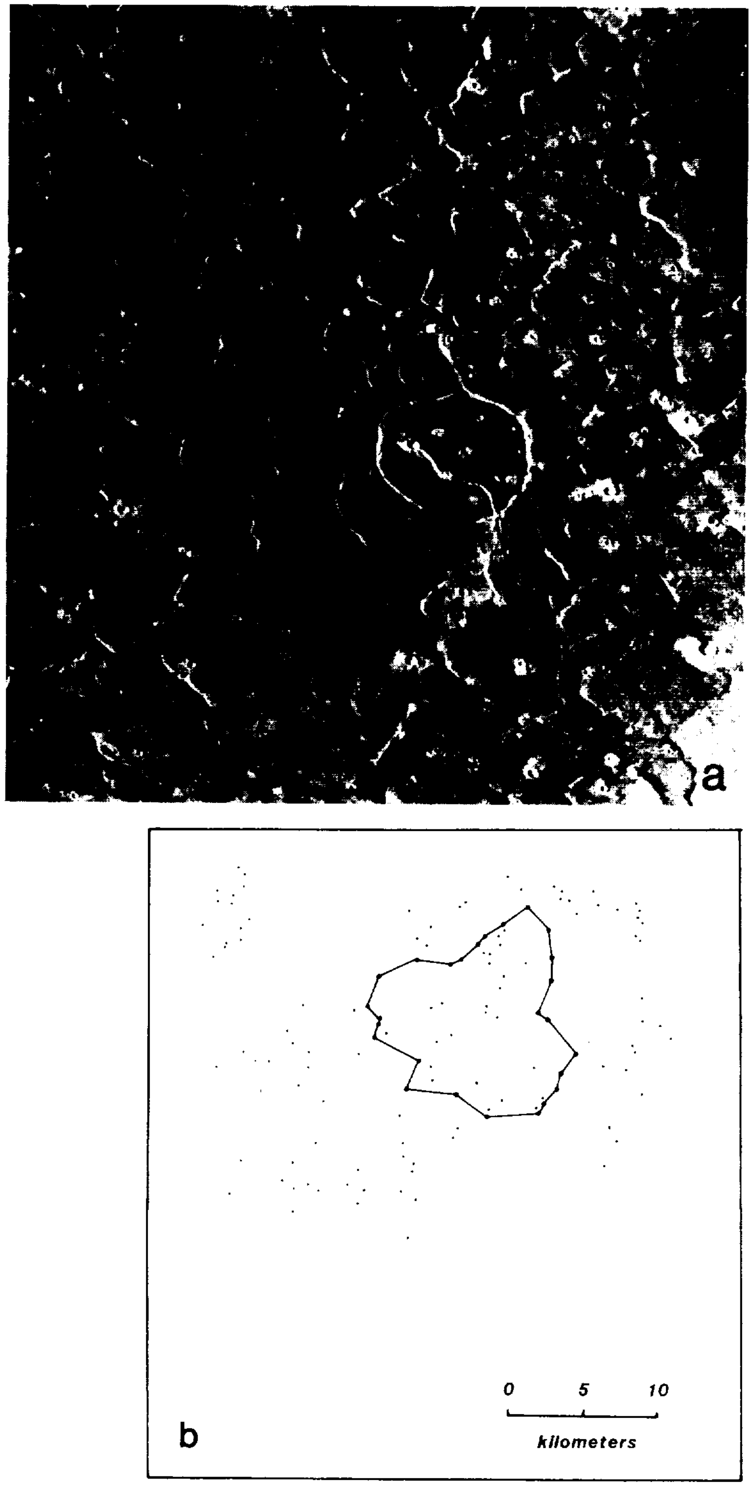

Fig. 2. Illustration of the method for determining nearest-neighbour statistics. (a) Pattern of large-scale polygonal fractures in Acidalia Planitia, in the northern plains of Mars. The area shown is about 50 km across (Viking photo 32A18, centered at 44°N, 18°W). (b) Location of vertices of cracks and outline of the area to be treated by nearest-neighbour analysis (N=51). The area does not include the entire pattern to avoid the boundary problem, as discussed in the text. The value of R here is 1.21 (more regular than random).

TABLE 1. NEAREST-NEIGHBOUR STATISTICS FOR POLYGONAL PATTERNED GROUND

Location	Probable origin of pattern	Source of data	Nearest-neighbour statistic, R	Statistical significance of departure from random
Northern Norway	Ice wedging	Öhrngren, 1967, Fig. 2	1.11	0.01 confidence level - random
N.W.T., Canada	Thermal contraction	Kerfoot, 1972, Fig. 4	1.15	0.01 confidence level - random
Southern Sweden	Thermal contraction	Svensson, 1977, Fig. 8	1.17	0.05 confidence level - random
Acidalia Planitia Mars	Unknown	Viking Orbiter Image 32A18	1.21	MRR*
Northern Norway	Thermal contraction	Svensson, 1962, Fig. 1	1.32	MRR
Northern Alaska U.S.A.	Ice wedging	Lachenbruch, 1962 Fig. 2	1.50	MRR
Northern Norway	Ice wedging	Maack, 1967, Fig. 4	1.52	MRR
Deuteronius Mensae Mars	Unknown	Lucchitta, 1983 Fig. 2b	1.57	MRR
Northern Finland	Thermal contraction	Seppälä, 1982, Fig. 7	1.58	MRR
Southern Sweden	Ice wedging	Rapp and Annersten, 1969, Fig. 4	1.65	MRR
Chryse Planitia Mars	Unknown	Brook, 1982, Fig. 1b	1.86	MRR

*MRR = Statistically more regular than random in pattern.

hexagonal lattice. The only statistically significant values of R will occur around these clustered, random, and regular nodes (Fig. 1). Values outside the 0.05 confidence level for the standard variate of a normal curve can be grouped as MCR, more clustered than random ($\bar{r}_A < \bar{r}_E$), or MRR, more regular than random ($\bar{r}_A > \bar{r}_E$) (Clark and Evans 1954; Vitek 1973*a*, *b*). An underlying assumption of this nearest-neighbour analysis is that a random density has a Poisson distribution (Clark and Evans 1954).

Previous nearest-neighbour studies for other types of ground patterns have used the centers of the features as points in the pattern. For polygonal ground, each vertex and intersection should be treated as a point. This technique is illustrated in Figure 2.

The boundary problem

Selection of the area covered by the pattern being studied is an important part of the analysis. Clark and Evans (1954) and Vitek (1973*b*) showed that it must be delineated carefully because the area affects the statistics. Including area that is not part of the pattern reduces the value of R; in an extreme case, a large excess area surrounding a relatively small pattern will cause R to approach 0.00, the clustered node. To avoid this bias, the outline should extend no farther than the outer limits of the pattern (Fig. 2*b*). This eliminates areas that are not involved in a pattern and might have been formed by a different process, as well as helping ensure that the density and R-statistic are representative of the pattern (Vitek 1973*b*).

Aplin (1983) also discusses the boundary problem. He advocates the use of a "buffer zone" around the area being measured, but he emphasizes that establishing such a border sometimes has the negative effect of seriously reducing the total number of points in a pattern. Points occurring in the pattern but outside of the outlined area should be included in the analysis. This approach is illustrated in Figure 2*b*.

The nearest-neighbour statistic

The nearest-neighbour statistic, R, has been calculated for a sample of areas with polygonally patterned ground in Scandinavia and North America, as well as on the planet Mars. The results are shown in Table 1, which also includes the location and inferred origin of the features. Also shown is the statistical significance of the departure from a randomly distributed population. The measured patterns were selected by the availability of published maps, aerial photographs, or spacecraft images that included the scale and an interpretation of the origin of the polygons. The calculated values of R range from statistically significant random values of 1.11 and 1.15, which fall within the 5 per cent level of significance for those populations (Clark and Evans 1954), up to 1.86, which is classified as more regular than random (MRR).

Discussion

Nearest-neighbour analysis should prove to be a valuable tool in quantifying polygonally patterned ground. The nearest-neighbour analysis allows comparison of patterns between and among areas. Vitek (1973*b*) noted that such pattern analysis may ultimately provide some insight into the role of climate and material in the formation of patterned ground.

The term "random" has often been used to describe polygonal systems. Lachenbruch (1962) introduced a classification system separating polygonal ground into "random orthogonal systems" and "oriented orthogonal systems." The random systems develop under a relatively low applied stress, and new fractures propagate across the surface "... in a random manner, generally following loci of low strength" (Lachenbruch 1962, p. 46).

Using this description to distinguish random patterns from oriented ones can be confusing; the qualitative or statistical aspect must be specified. When Lachenbruch's (1963) examples of random-orthogonal and oriented-orthogonal systems are analyzed by the nearest-neighbour technique, they all have R values in the MRR range (Table 1). This is also a problem in some of the planetary-geology literature. For example, Lucchitta (1983) describes Martian polygons in Deuteronilus Mensae as random-orthogonal patterns, but nearest-neighbour analysis gives an R value of 1.57, which is more regular than random. Lachenbruch's (1962) classification system is certainly valid, but the terminology must be carefully defined to avoid confusing subjective descriptions with quantitative statistics.

An immediate advantage of the nearest-neighbour statistical analysis of patterned ground is that it eliminates the effect of scale. Descriptions of patterned ground on Mars, for example, have always been influenced by the size of the polygons, which range up to 20 km or more in diameter. The R-statistic is dimensionless, and therefore direct comparisons between terrestrial and Martian patterns can be made. Patterns with a range of origins can also be compared with each other, including periglacial patterned ground, large- and small-scale desiccation polygons, cooling fractures in lava, and tectonic features. Measurements of polygons with these various origins should add significantly to comparative pattern analysis. A valuable contribution from this technique should be in helping to define the roles of climate, process, and materials in pattern development.

Conclusions

Nearest-neighbour analysis is a quantitative procedure to determine how much a pattern departs from an expected random pattern. Polygonal ground patterns in Scandinavia, North America, and the northern plains of Mars have nearest-neighbour statistics that range from statistically random (within the 0.01 confidence level) to more regular than random. Differences in R between otherwise-similar areas can lead to the identification of important factors in the development of polygonal features. Nearest-neighbour analysis may eventually prove useful in interpreting the climate, material, and processes that created a particular pattern.

A major advantage of the nearest-neighbour analysis for patterned ground is that it allows quantitative comparisons between patterns. Because the analysis eliminates the effect of pattern size, it can be effectively applied to terrestrial patterns formed by desiccation, lava cooling, and tectonism, as well as polygonal patterns of unknown origin that are found on the surfaces of other planetary bodies.

Acknowledgements

This work was funded in part by grants NAGW-517 and -715 from the National Aeronautics and

Space Administration (Planetary Geology and Geophysics Program). Suggestions and manuscript reviews by John Vitek, Dallas Rhodes, Michael Woldenberg, and William Wadsworth are gratefully acknowledged. The Viking image used in Figure 2 was provided through the National Space Science Data Center and Michael Carr, Viking Imaging Team Leader. Most of this work was conducted as a visiting researcher at the Department of Physical Geography, University of Uppsala, Sweden, and special thanks go to Professor Åke Sundborg for making that possible.

Assistant Professor Lisa A. Rossbacher, Geological Sciences Department, California State Polytechnic University, Pomona, California 91768 USA.

References

Aplin, G., 1983: Order-neighbor analysis. *Concepts and techniques in modern geography*, Nr. 36. 38 p.

Barr, B. M., Lindsay, I. J., and *Reinelt, E. R.*, 1971: Patterns of urban spacing in the U.S.S.R.: Analysis of order neighbor statistics in two-dimensional space. *J. Regional Sciences* 11:211–224.

Brook, G. A., 1982. Ice-wedge polygons, baydjarakhs, and alases in Lunae Planum and Chryse Planitia, Mars. *NASA Tech. Memo.* 85127:265–267.

Clark, P. J., and *Evans, F. C.*, 1954: Distance to nearest neighbour as a measure of spatial relationships in populations. *Ecology* 35:445–452.

Getis, A., 1963: The determination of location of retail activities with the use of a map transformation. *Econ. Geography* 39:14–22.

Kerfoot, D. E., 1972: Thermal contraction cracks in an arctic tundra environment. *Arctic* 25: 142–150.

Lachenbruch, A. L., 1962: Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost: *Geol. Soc. America Spec. Paper* 70. 69 p.

—1963: Contraction theory of ice-wedge polygons: A qualitative discussion. *In*: Permafrost: International Conference, Proc. Nat. Acad. Sci., Washington: 63–71. 563 p.

Lucchitta, B. K., 1983: Permafrost on Mars: Polygonally fractured ground. *In:* Permafrost: Fourth International Conference, Proc. Nat. Acad. Press, Washington: 744–749.

Maack, A., 1967: Polygonal ground and solifluction features: Fossil ice-wedge polygons in the Kunes and Båtsfjord areas. *Lund Studies in Geography* 40A:41–57.

Öhrngren, S., 1967: Polygonal ground and solifluction features: Polygon fields on the Laksefjord, Finnmark. *Lund Studies in Geography* 40A:58–67.

Rapp, A., and *Annersten, L.*, 1969: Permafrost and tundra polygons in Sweden. *In:* Péwé, T. L. (ed.): *The periglacial environment.* McGill-Queen's Univ. Press, Montreal:65–91.

Seppälä, M., 1982: Present-day periglacial phenomena in northern Finland. *Biul. Peryglacjalny* 29:231–243.

Smalley, I. J., and *Unwin, D. J.*, 1968: The formation and shape of drumlins and their distribution and orientation in drumlin fields. *Glaciol.* 7:377–390.

Svensson, H., 1962: Note on a type of patterned ground on the Varanger Peninsula, Norway. *Geogr. Ann.* 44:413.

—1977: Observations on polygon fissuring in non-permafrost areas of the Norden countries. *Akad. Wiss. Göttingen Abh., Math.-Phys. Kl.* 31:63–76.

Trenhaile, A. S., 1971: Drumlins: Their distribution, orientation, and morphology. *Can. Geogr.* 15:113–126.

Vitek, J. D., 1973*a*: The mounds of south-central Colorado: An investigation of geographic and geomorphic characteristics. Ph. D. diss., Univ. Iowa. 229 p.

—1973*b*: Patterned ground: A quantitative analysis of patterns. *Assoc. Am. Geographers Proc.* 5:272–275.

Washburn, A. L., 1956: Classification of patterned ground and review of suggested origins. *Geol. Soc. America Bull.* 67:823–865.